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NOAA/NESDIS Operational Advanced-TOVS (ATOVS) Polar Orbiter Sounding Products

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1.0 INTRODUCTION

Since 1979, the NESDIS operational sounding products from NOAA's polar orbiting satellites have provided a continuous suite of infrared and microwave radiation sounder measurements, and derived temperature and moisture sounding products on a global scale. These data represent a unique source of global, atmospheric, weather information, with a demonstrated positive impact on Numerical Weather Prediction (NWP) forecasts, NOAA's primary mission for sounding products. In May, 1998, the ATOVS instrument configuration onboard NOAA-15 was successfully deployed, followed by NOAA-16 in September, 2000. ATOVS consists of the new 15-channel Advanced Microwave Sounding Unit-A (AMSU-A), the new 5-channel AMSU-B for atmospheric moisture, the HIRS/3 and the AVHRR /3. ATOVS sounding products from NOAA-15 were operationally implemented by NESDIS in April, 1999 (Reale et al. 1999a and 1999b). AMSU-B processing was delayed until May, 2000 (Chalfant et al.1999 and Reale et al. 2000b). This report summarizes the ATOVS sounding product systems and scientific algorithms operated by NESDIS.

1.02 ATOVS SCIENTIFIC ALGORITHMS

Two product systems are currently operated, **ATOVS-A**, which processes sounding products using the HIRS, AMSU-A and AVHRR radiometers (Reale et al. 2000a), and **ATOVS-B,** which processes (moisture) sounding products using the AMSU-B radiometer (Chalfant et al. 1999). The scientific procedures for each system are comprised of two primary subsystems for **Orbital** and **Offline** support processing, respectively.

2.1 Orbital Processing

The orbital processing system consists of five steps:

- Preprocessing
- Radiance Temperature Adjustments
- Contamination Detection
- First Guess Computation
- Retrieval Computation

Preprocessing for each orbital system is done on the raw, level-1b satellite data. Preprocessing steps include the application of the calibration coefficients and, the computation of the radiance and radiance temperature measurements. In addition, preprocessing for ATOVS-B includes the correction of AMSU-B measurements for Radio Frequency Interference (RFI) from data transmitters onboard NOAA-15 (Atkinson 1999 and 2000). AMSU-B data from NOAA-16 have no RFI.

Limb adjustments are then applied to the calibrated, radiance temperature measurements from HIRS/3, AMSU-A and AMSU-B (Wark 1993 and Allegrino et al. 1999. The limb corrected measurements for AMSU-B are also adjusted to remove perceived bias relative to radiative transfer model calculations (Fleming et al. 1991).

The contamination detection step is done separately for microwave and infrared sensor data. Microwave contamination detection primarily consists of identifying localized anomalies in AMSU sounding channels sensitive in the lower troposphere typically due to precipitation and large ice particles (Grody et al. 1999). Infrared measurements are screened for cloud contamination by methods described in Ferguson and Reale, 2000.

The first guess computation is uniquely determined for each ATOVS-A and ATOVS-B sounding using a library search technique (Goldberg et al. 1988). The first guess libraries consist of collocated radiosonde and satellite observations, which are directly accessed during orbital processing and updated daily.

The matrix equation for the library search is given in (1):

$$D = (R - R_k)^t \ B^{-1} \ (R - R_k) \qquad (1)$$

where the subscript *t* indicates the matrix transpose and

D: scalar closeness parameter,
B: sounding channel radiance covariance matrix
R: adjusted, observed radiance temperature vector
R_k: adjusted, library radiance temperature vector

The first guess temperature, moisture and radiance temperature profiles for a given sounding are computed by averaging the 10 closest collocations; that is, those with the smallest "D". Radiosonde averages are used for temperature and moisture, and the adjusted measurements from the sounder are averaged for radiance temperature.

In the retrieval step, the general form of the retrieval equation is given by (2):

$$T - T_g = C\,(R - R_g) \qquad (2)$$

where T and R are product and measurement parameters, the subscript "g" an apriori estimate, and C is the solution.

The ATOVS-A retrieval method is the Minimum-Variance-Simultaneous (MVS) solution (Smith et al. 1984 and Fleming et al. 1986) given by matrix equation (3):

$$\begin{aligned} T - T_g &= S A^t \, (A S A^t + N)^{-1} \, (R - R_g) \qquad (3) \\ &= X \quad (\quad Y \quad)^{-1} \, (R - R_g) \end{aligned}$$

where the subscript *t* indicates the matrix transpose, and:

T: final soundings products vector, (151),
T_g: first guess products vector, (151)
S: first guess covariance matrix, (151 x 151),
A: sounder channel weighting matrix, (35 x 151),
N: measurement noise covariance matrix, (35 x 35),
R: observed radiance temperature vector
R_g : first guess radiance temperature vector
X,Y: pre-computed retrieval operator components.

The product vector (T) contains 100 levels of atmospheric temperature (1000 mb to .1 mb), 50 levels of moisture (1000 mb to 200 mb), and the surface level. The dimension 35 for the A and N matrices denotes all the ATOVS channels; not all are used. The first guess and observed channels used in the retrieval solution, depend on the sounding type.

The ATOVS-B retrieval utilizes an ordinary least squares solution of equation 2, where:

T: water vapor mixing ratio sounding products vector
T_g: first guess mixing ratio vector
C: statistical regression coefficients
R: observed radiance temperature vector
R_g : first guess radiance temperature vector

The product vector (T) includes 15 levels of atmospheric moisture (1000 to 300 mb). Two sets of regression coefficients are available, for sea and non-sea soundings respectively.

The original calibrated sounder measurements, the adjusted sounder measurements, the first guess information, the derived temperature and moisture soundings and the appended ancillary data (i.e. cloud mask, AVHRR, SST, etc.) are operational products that are routinely distributed to users. The dedicated links for these data are NOAA-EMC, the United Kingdom Meteorological Office (UKMO) (Bracknell, England), the Global Telecommunications System (GTS) and the Shared Processing Network (SPN).

2.2 Offline Processing

The offline systems contribute the tuning and validation functions required to maintain the scientific integrity of the sounding products. Offline systems routinely compile and maintain data sets comprised of

- Satellite Radiance Databases
- Satellite and Radiosonde Collocations
- Coefficients

The Satellite Radiance Database Sets are separately maintained for HIRS/3, AMSU-A and AMSU-B radiometer data. These data sets contain adjusted and non-adjusted radiance temperature measurements for the respective instruments, typically spanning the latest 30 to 60 days. Each data set is updated at the conclusion of orbital processing at about a 50% sub-sampling rate, excluding polar-redundant and high terrain (>1000m) observations.

Collocated radiosonde and satellite observations are extensively used in the derivation and validation of the operational sounding products. The steps to compile and utilize collocated radiosonde and satellite observations include the radiosonde collocation processing and, updating the Matchup Data Bases (MDB) and the First Guess Libraries.

In the radiosonde collocation process, the radiosonde reports are processed daily. Accepted radiosonde reports are candidates for collocation with satellite data. A collocated radiosonde and satellite observation is compiled if the candidate radiosonde and satellite sounding data meet the criteria described in Tilley et. al., 2000.

The Matchup Data Bases (MDB), supporting the ATOVS-A and ATOVS-B products systems, respectively, provide the longer term data sets of radiosonde and satellite data collocations used for the tuning and validation of derived sounding products (Tilley et al. 2000 and Reale et al. 1990). Each MDB is updated daily. The ATOVS-A system maintains separate MDB's for clear and cloudy collocations, which are stratified among 23 geographical categories. On the other hand, the ATOVS-B system maintains a single MDB where collocations are stratified by sea and non-sea.

The First Guess Libraries are updated daily based on the MDBs, and directly accessed during orbital processing. The first guess libraries have about half of the capacity of the MDBs, with an additional requirement that the vertical extent of a candidate radiosonde report be complete from (at least) 950 mb to 50 mb for ATOVS-A, and from 950 mb to 400 mb for ATOVS-B, respectively. A new approach based on a statistical regression of the collocated AMSU-A measurements (Goldberg 1999) was deployed for NOAA-15 during April 2000 to extend each radiosonde from the highest report level to .1 mb. The downward extension of a radiosonde is only required if the first significant level is between 950 and 1000 mb, and is done using a weighted, averaged, lapse rate and constant dewpoint depression for temperature and moisture, respectively, based on the lowest reported levels.

Various offline systems also compute coefficients for the derivation of operational sounding products. Coefficients are required for limb adjustment, cloud detection (Ferguson and Reale, 2000), the first guess (Goldberg et al. 1988), the retrieval (Fleming et al, 1986 for ATOVS-A and Goldberg et al. 1998 for ATOVS-B), AMSU-B radiance bias adjustment (Fleming et al. 1991 and McMillin et al. 1989, using the approach of Crone et al. 1996), and, RFI correction (AMSU-B for NOAA-15). Except for limb adjustment and RFI correction, all coefficients are updated weekly.

3.0 RESULTS

The scientific monitoring and evaluation of operational sounding products is maintained on a continuous basis at NESDIS. The primary evaluation strategy is the vertical accuracy statistics. Vertical accuracy statistics, based on satellite minus radiosondes differences computed from collocations stored on the MDB, are illustrated in Figures 1 and 2. These provide estimates of the expected performance of NESDIS operational soundings on a global scale. Figure 1 shows differences for ATOVS-A clear temperature soundings from the 60N to 60S latitude belt. Figure 3 shows differences for ATOVS-B moisture soundings for the 30N to 30S latitude belt. The thicker curves for each plot are for the final soundings, and the thinner lines for the corresponding first guess profiles, respectively. Figure 2 provides mean and standard deviation differences in degrees K, whereas the Figure 3 plots are percent differences in water vapor mixing ratio (g/kg), with the mean profiles used to compute percentages shown along the inside of the left axis. Pressure (mb) and sample size are indicated along the left and right vertical axis for all plots.

Figure 1 indicates that satellite minus radiosonde differences approach 2.5 K (RMS) near the surface and troposphere, 1.5 K in the middle troposphere where the sounders are most reliable, and about 2.0 K in the stratosphere. Little or no bias is present except at the tropopause. Figure 2 indicates expected uncertainties for moisture near the surface to be about 15 percent in the tropics. However, when multiplied by the mean mixing ratio values, the actual differences in water mixing ratio units is about 2 g/kg in the tropics. The steady increase in the percentage uncertainty of moisture with height is also attributable to the relatively low mixing ratio values aloft. Factoring in the spatial and temporal windows for each collocation, the inherent variability of moisture measurements, and radiosonde moisture errors, the accuracy estimates shown in Figure 2 are reasonable.

Significantly improved accuracy of the final soundings (thick curves) compared to the guess (thin curves) in Fig. 1 confirms the scientific approach, in particular, the consistency of the first guess radiance temperature and temperature observations provided for the retrieval step (Fleming et al. 1986).

4.0 FUTURE PLANS

The primary scientific activity planned over the next year is the merging of the ATOVS-A and B systems into a single, simultaneous, temperature and moisture products generation system. This will include studies to replace the library search with a statistical regression technique based on AMSU, and if successful, the replacement of pre-computed with real-time retrieval operators. Referred to as System-2002, the proposed upgrade would result in dual sounding products, consisting of climate oriented first guess information, and real-time weather oriented derived products, the later optimized for assimilation into NWP. There are also new requirements to provide ATOVS processing fall back contingencies, particularly in the event of a HIRS sounder failure

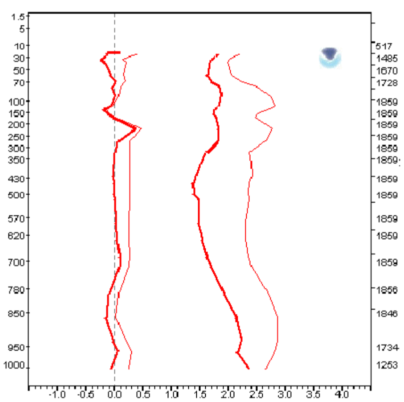

Figure 1: ATOVS-A Clear Statistics

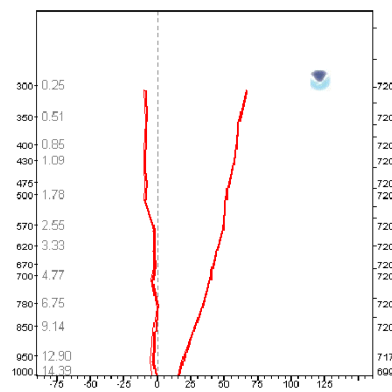

Figure 2: ATOVS-B Tropical Statistics

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